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Authors: Crooks, Kevin R., Scott, Cheryl A., Bowen, Lizabeth, and Van Vuren, Dirk

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Hematology and Serum Chemistry of the Island Fox on Santa Cruz Island

Kevin R. Crooks,[1,5] **Cheryl A. Scott,**[2] **Lizabeth Bowen,**[3] **and Dirk Van Vuren**[4] [1] Department of Biology, University of California, Santa Cruz, California 95064; [2] P.O. Box 73842, Davis, California 95617; [3] John Muir Institute of the Environment, University of California, Davis, California 95616; [4] Department of Wildlife, Fish, and Conservation Biology, University of California, Davis, California 95616; [5] Corresponding author (e-mail: krcrooks@earthlink.net).

ABSTRACT: Serum and hematologic biochemistry values for island foxes (*Urocyon littoralis*) on Santa Cruz Island (California, USA) in April (wet season) and September (dry season) 1998 were evaluated. Serum chemistry of island foxes generally varied seasonally; 10 (40%) of the 25 serum characteristics were higher in the wet season, and three (12%) of the 25 serum characteristics were higher in the dry season. No hematologic parameters varied between seasons, although some measures varied between sexes. Blood analytes also varied with age; fox pups had higher values than adults for one hematologic and four serum parameters, whereas adult foxes had higher values for five hematologic characteristics. The information on blood chemistry provides baseline data useful in the monitoring of this threatened insular endemic carnivore.

Key words: Blood, island fox, hematology, serum chemistry, *Urocyon littoralis.*

The island fox (*Urocyon littoralis*), an insular endemic relative of the mainland gray fox (*Urocyon cinereoargenteus*), occurs on the six largest of the eight California Channel Islands (USA). The continued existence of this species is uncertain. Due to restricted distribution and small population sizes, the island fox has been listed as threatened by the state of California. Because the status of island foxes is precarious, monitoring their populations and identifying key threats to their persistence are essential. Blood analyses may be used to assess the health and physiological condition of wild canids, and may indirectly serve as indicators of nutrition, disease, trauma, habitat quality, and other environmental stressors (Seal et al., 1975; Gates and Goering, 1976; Smith and Rongstad, 1980; DelGiudice et al., 1991; McCue and O'Farrell, 1987, 1992). However, baseline ranges of these parameters must be established before such data can be interpreted and applied.

Basic serum chemistry and hematologic characteristics for the island fox have not been previously reported. Indeed, we are aware of no detailed study of blood characteristics of gray foxes on the mainland. The objectives of this study were to determine serum and hematologic biochemistry values for the island fox on Santa Cruz Island (California, USA). We then evaluated the effect of season, sex, and age on these parameters.

Santa Cruz Island (34°0′N, 119°45′W), the largest of the California Channel Islands, is located 40 km south of Santa Barbara, California. The island is 39 km long and 3 to 11 km wide (250 km^2) and has a system of interior valleys, including the large Central Valley, oriented in an east-west direction and bounded by mountain ranges on the north (maximum elevation 750 m) and the south (465 m). Although 10 plant communities have been described (Junak et al., 1995), most of the island supports grassland, chaparral, and coastal sage scrub communities (Minnich, 1980). Climate is a maritime, Mediterranean type with hot, dry summers and cool, wet winters.

In April (wet season) and September (dry season) 1998, we sampled foxes along road transects that totaled about 30 km in length throughout the central portion of the island. Foxes were live-trapped in single-door box-traps set every 250 to 500 m and baited with commercial cat food and fruit paste baits. Foxes were docile and could be manually restrained during processing without the use of anesthesia. Captured foxes appeared healthy based on a brief physical exam. Age class of each fox was estimated by tooth eruption and wear of the first upper molar by utilizing an aging protocol initially developed for mainland gray foxes (Wood, 1958) and previously applied to island foxes (Crooks, 1994). Foxes were classified as pups (less than one year old) or adults (one year or older). Foxes are typically born in May and June (Laughrin, 1977), so fox pups captured in September were about 3 to 4 months old, and fox pups captured in April were 10 to 11 months old.

We collected 4 to 6 ml of blood from the jugular vein on all captured foxes. For each fox, half of the blood drawn was stored in tubes treated with the anticoagulant ethylene diamine tetra-acetic acid (EDTA), and the other half was centrifuged in serum-separator tubes for 10 min. at 3,000 rpm. Samples were refrigerated until analyses were conducted 1–6 days following collection by Idexx Veterinary Services (West Sacramento, California, USA). Hematological analyses were conducted on EDTA plasma by an Abbott Cell-Dyn analyzer (Abbott Laboratories, Abbott Park, Illinois, USA), and serum biochemical analyses were performed by a Hitachi 747-200 analyzer (Roche Diagnostics, Indianapolis, Indiana, USA). Blood smears were made at the time of collection, and differential counts were performed manually.

The following hematologic measures were calculated: white blood cell (WBC), red blood cell (RBC), hemoglobin (Hb), hematocrit (HCT), mean corpuscular volume (MCV), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), neutrophil, lymphocyte, monocyte, eosinophil, and basophil. Serum samples were analyzed for concentrations of alkaline phosphatase (ALP), alanine aminotransferase (ALT), aspartate aminotransferase (AST), creatinine kinase (CK), gamma-glutamyltransferase (GGT), total protein, albumin, globulin, albumin : globulin ratio, bilirubin, blood urea nitrogen (BUN), creatinine, BUN : creatinine ratio, cholesterol, glucose, calcium, phosphorous, bicarbonate, chloride, potassium, sodium, sodium : potassium ratio, and anion gap. We calculated mean, standard errors, and standard deviations for each blood characteristic; all values were log-transformed for statistical analyses. We first conducted two-way ANOVA to test for the effects of season (wet and dry), sex, and season-sex interactions on parameter values for all foxes. We then conducted *t*-tests to compare parameter values between pups and adults. *A* value of $P < 0.05$ was considered statistically significant, and $0.05 < P < 0.10$ was considered marginally significant.

Table 1 provides hematologic and serum chemistry profiles for each season and sex for the 49 captured island foxes. Wet season serum chemistry values were significantly higher than dry season values for ALT ($P = 0.042$), AST ($P = 0.012$), albumin ($P = 0.006$), albumin : globulin ratio ($P = 0.024$), BUN ($P < 0.001$), BUN : creatinine ratio ($P < 0.001$), cholesterol ($P = 0.001$), and glucose ($P < 0.001$); CK concentrations also tended to be higher in the wet season ($P = 0.087$). Conversely, chloride concentrations were significantly higher in the dry season ($P = 0.021$); ALP ($P = 0.053$) and globulin ($P = 0.089$) also tended to be higher in the dry season. Mean serum chemistry values did not differ between sexes for any variable ($P > 0.10$). However, season by sex interactions were marginally significant for glucose ($P = 0.099$: a greater increase in glucose concentration in the wet season for females than for males) and chloride ($P = 0.065$: a greater decrease in chloride concentrations in the wet season for females than for males).

Hematologic values for males were significantly greater than for females for RBC ($P < 0.001$), Hb ($P < 0.001$), and HCT ($P < 0.001$). Conversely, MCV was significantly greater for females ($P = 0.003$); absolute basophil also tended to be higher in females ($P = 0.077$). Mean hematologic values did not differ between seasons for any variables ($P > 0.10$). However, significant season by sex interaction effects were evident for RBC ($P = 0.011$: a decrease in female and an increase in male RBC concentration from dry to wet season), Hb ($P = 0.009$: a decrease in female and an increase in male Hb concentration from dry to wet season), HCT ($P = 0.025$: a decrease in female and an increase in male HCT concentration from dry to wet season), and absolute lymphocyte ($P = 0.040$: an increase in female and a decrease in male lymphocyte concentration from dry to wet season); season by sex interactions were marginally significant for MCV ($P = 0.098$: an increase in female and a decrease in male MCV from dry to wet season) and WBC ($P = 0.072$: an increase in female and a decrease in male WBC concentration from dry to wet season).

Table 2 provides serum chemistry and hematologic profiles for the 38 adult and 11 pup island foxes. Pup serum chemistry values were significantly higher than adult values for ALP ($t = 4.78$, $P < 0.001$), creatinine ($t = 3.81$, $P < 0.001$), calcium ($t = 4.72$, $P < 0.001$), and phosphorous ($t = 6.01$, $P < 0.001$); percent lymphocytes also tended to be higher in pups ($t = 1.96$, $P = 0.056$). Adult hematologic values were significantly higher than pup values for MCH ($t = 2.81$, $P = 0.007$), percent monocytes ($t = 2.35$, $P = 0.023$), and absolute monocytes ($t = 2.14$, $P = 0.038$); MCV ($t = 1.86$, $P = 0.069$) and MCHC ($t = 1.76$, $P = 0.086$) also tended to be higher in adults.

Serum chemistry values varied seasonally in the island fox; of the 25 serum characteristics, nine were higher in the wet season and three were higher in the dry season. Similarly, serum characteristics varied seasonally in San Joaquin kit foxes in California (McCue and O'Farrell, 1992). Male and female island foxes did not differ in serum chemistry values. Serum characteristics also did not differ between sexes in kit (McCue and O'Farrell, 1992) or captive swift (Mainka, 1988) foxes, although some serum characteristics values varied between sexes in red (Benn et al., 1986) and silver (Zhan et al., 1991) foxes. Serum chemistry parameters also varied with age in the island fox; elevated levels of ALP, phosphorous and calcium in pups are likely associated with increased rate of bone formation and osteoblast differentiation in younger animals (Seal et al., 1975; Smith and Rongstad, 1980; Kirk et al., 1990).

Hematology varied between sexes in the island fox; of the 17 hematologic characteristics, three were higher for males, and two were higher for females. Some hematologic characteristics also varied between sexes in swift (Mainka, 1988) and red (Kennedy, 1935) foxes, but did not in San Joaquin kit foxes (McCue and O'Farrell, 1987) or silver foxes (Zhan et al., 1991). Like island foxes, female swift foxes had larger red blood cells (MCV) than did male swift foxes (Mainka, 1988). Although hematologic measures did not differ between seasons in the island fox, hematology varied seasonally in kit foxes (McCue and O'Farrell, 1987) and captive wolves (Seal and Mech, 1983). Hematologic parameters also varied with age in the island fox; adults tended to have larger erythrocytes, higher concentrations of hemoglobin in erythrocytes, and higher proportion of monocytes, whereas pups tended to have higher proportion of lymphocytes. Like island foxes, hemoglobin levels also increase with age in silver (Spitzer et al., 1941), red (Kennedy, 1935), and San Joaquin kit (Jain, 1986) kit foxes.

Typical of other insular fauna, the island fox is particularly vulnerable to local extinction due to small population sizes, restricted distribution, low genetic diversity, and little exposure and acquired immunity to a range of pathogens (Wayne et al., 1991; Garcelon et al., 1992; Crooks, 1994; Crooks and Van Vuren, 1994). The vulnerability of island foxes highlights the urgent need to monitor their populations and enact management and conservation plans accordingly. The data on blood chemistry presented in this paper should

TABLE 1. Serum chemistry and hematologic profiles of island foxes on Santa Cruz Island (California, USA) in 1998.

	Dry season							
	Female				Male			
	Mean	SE[a]	SD[b]	*n*	Mean	SE	SD	*n*
Serum chemistry								
ALP (IU/L)	29.82	8.73	28.96	11	39.75	15.28	52.95	12
ALT (IU/L)	91.36	14.30	47.44	11	88.33	11.55	40.02	12
AST (IU/L)	85.00	11.65	38.64	11	69.92	5.01	17.37	12
CK (IU/L)	786.18	193.06	640.30	11	463.67	62.93	218.00	12
GGT (IU/L)	1.91	0.37	1.22	11	1.42	0.36	1.24	12
Total protein (g/dL)	8.04	0.39	1.30	11	8.06	0.33	1.14	12
Albumin (g/dL)	2.62	0.06	0.21	11	2.61	0.07	0.23	12
Globulin (g/dL)	5.42	0.42	1.40	11	5.45	0.38	1.32	12
Albumin : globulin ratio	0.52	0.05	0.17	11	0.52	0.05	0.16	12
Total bilirubin (mg/dL)	0.10	0.00	0.00	11	0.10	0.00	0.00	12
Direct bilirubin (mg/dL)	0.09	0.01	0.03	11	0.07	0.01	0.05	12
Indirect bilirubin (mg/dL)	0.01	0.01	0.03	11	0.03	0.01	0.05	12
BUN (mg/dL)	13.18	1.90	6.29	11	13.00	0.95	3.28	12
Creatinine (mg/dL)	0.65	0.02	0.05	11	0.71	0.01	0.05	12
BUN : Creatinine ratio	19.96	2.69	8.91	11	18.38	1.25	4.33	12
Cholesterol (mg/dL)	133.36	8.25	27.36	11	121.67	6.18	21.42	12
Glucose (mg/dL)	75.36	8.71	28.89	11	77.83	7.95	27.55	12
Calcium (gm/dL)	8.72	0.16	0.54	11	8.80	0.15	0.52	12
Phosphorus (mg/dL)	4.30	0.46	1.54	11	4.53	0.47	1.63	12
Bicarbonate (mEq/L)	17.36	0.75	2.50	11	18.75	0.62	2.14	12
Chloride (mEq/L)	114.64	1.37	4.54	11	114.17	0.76	2.62	12
Potassium (mEq/L)	4.15	0.08	0.28	11	4.12	0.10	0.36	12
Sodium (mEq/L)	146.82	1.20	3.97	11	146.50	0.50	1.73	12
Sodium/potassium ratio	35.55	0.55	1.81	11	35.75	0.84	2.90	12
Anion gap (mEq/L)	19.09	1.10	3.65	11	17.75	0.52	1.82	12
Hematology								
WBC ($10^3/\mu L$)	14.20	0.88	2.91	11	16.18	0.82	2.84	12
RBC ($10^6/\mu L$)	6.30	0.14	0.47	11	6.62	0.18	0.61	12
Hb (g/dL)	12.74	0.29	0.98	11	13.18	0.35	1.21	12
HCT (%)	40.31	0.86	2.85	11	41.77	1.19	4.12	12
MCV (fL)	64.00	0.66	2.19	11	63.08	0.47	1.62	12
MCH (pg)	20.23	0.24	0.79	11	19.96	0.21	0.72	12
MCHC (g/dL)	31.64	0.34	1.13	11	31.60	0.21	0.71	12
Neutrophil (%)	76.36	2.38	7.90	11	72.42	2.25	7.80	12
Lymphocytes (%)	11.36	1.63	5.41	11	13.42	1.38	4.80	12
Monocytes (%)	4.00	0.71	2.37	11	4.33	0.50	1.72	12
Eosinophil (%)	6.91	1.33	4.41	11	9.17	1.43	4.95	12
Basophil (%)	2.75	1.18	2.36	4	1.60	0.60	1.34	5
Absolute neutrophil segment (per μL)	10,715.45	765.25	2,538.06	11	11,786.08	803.41	2,783.10	12
Absolute lymphocyte (per μL)	1,593.82	263.73	874.71	11	2,146.33	251.98	872.88	12
Absolute monocyte (per μL)	571.73	105.62	350.31	11	705.50	83.34	288.71	12
Absolute eosinophil (per μL)	972.64	189.89	629.79	11	1,449.17	210.14	727.94	12
Absolute basophil (per μL)	415.50	182.94	365.89	4	211.00	52.72	117.88	5

[a] Standard error.

[b] Standard deviation.

TABLE 1. Extended.

Wet season							
Female				Male			
Mean	SE	SD	*n*	Mean	SE	SD	*n*
14.13	0.87	3.36	15	15.45	2.20	7.29	11
93.07	7.70	29.80	15	138.64	26.55	88.06	11
93.73	9.82	38.02	15	106.64	12.33	40.89	11
1,210.60	376.30	1,457.40	15	911.27	212.39	704.41	11
2.33	0.25	0.98	15	2.09	0.16	0.54	11
7.43	0.14	0.56	15	7.75	0.08	0.25	11
2.70	0.06	0.21	15	2.86	0.04	0.12	11
4.73	0.13	0.50	15	4.89	0.07	0.24	11
0.58	0.02	0.08	15	0.58	0.02	0.06	11
0.10	0.00	0.00	15	0.09	0.01	0.03	11
0.01	0.01	0.04	15	0.02	0.01	0.04	11
0.09	0.01	0.04	15	0.07	0.01	0.05	11
20.33	2.08	8.07	15	22.18	3.58	11.88	11
0.65	0.02	0.07	15	0.66	0.02	0.07	11
31.33	2.99	11.56	15	32.72	4.73	15.68	11
166.33	9.65	37.37	15	148.73	7.74	25.67	11
149.60	12.63	48.90	15	106.91	6.10	20.24	11
8.52	0.11	0.41	15	8.70	0.11	0.36	11
3.67	0.16	0.61	15	4.13	0.27	0.90	11
17.67	0.83	3.22	15	18.00	0.85	2.83	11
111.73	0.75	2.89	15	112.64	0.77	2.54	11
4.24	0.06	0.23	15	4.17	0.07	0.22	11
144.40	0.69	2.67	15	147.18	0.81	2.68	11
34.07	0.55	2.12	15	35.27	0.59	1.95	11
19.20	1.20	4.65	15	20.64	0.95	3.14	11
17.07	1.18	4.59	15	15.01	1.41	4.67	11
5.70	0.19	0.75	15	6.91	0.13	0.44	11
11.43	0.33	1.26	15	13.61	0.31	1.03	11
36.99	1.05	4.07	15	43.05	0.82	2.73	11
65.27	0.64	2.49	15	62.27	0.62	2.05	11
20.14	0.27	1.05	15	19.65	0.18	0.61	11
30.95	0.23	0.89	15	31.58	0.23	0.77	11
77.67	2.19	8.47	15	78.91	2.82	9.36	11
11.00	1.44	5.57	15	9.00	1.36	4.49	11
4.36	0.69	2.59	14	4.10	0.72	2.28	10
6.43	1.27	4.75	14	6.73	1.34	4.43	11
2.38	0.53	1.51	8	2.00	0.29	0.87	9
13,498.00	1,176.54	4,556.71	15	12,022.36	1,325.95	4,397.69	11
1,814.07	232.41	900.11	15	1,271.09	156.08	517.67	11
722.50	107.11	400.78	14	641.30	165.52	523.41	10
1,024.92	179.18	646.03	13	916.64	142.75	473.44	11
444.56	93.26	279.78	9	264.00	21.21	63.62	9

TABLE 2. Serum chemistry and hematologic profiles of adult and pup island foxes on Santa Cruz Island (California, USA) in 1998.

	Adult				Pup			
	Mean	SE	SD	*n*	Mean	SE	SD	*n*
Serum chemistry								
ALP (IU/L)	14.29	0.79	4.89	38	58.55	15.93	52.85	11***
ALT (IU/L)	101.39	9.66	59.55	38	103.00	12.91	42.82	11
AST (IU/L)	91.76	6.09	37.55	38	78.73	9.49	31.46	11
CK (IU/L)	948.11	170.22	1,049.28	38	578.82	106.06	351.77	11
GGT (IU/L)	2.00	0.16	0.99	38	1.82	0.40	1.33	11
Total protein (g/dL)	7.80	0.10	0.62	38	7.77	0.48	1.59	11
Albumin (g/dL)	2.71	0.03	0.19	38	2.65	0.09	0.31	11
Globulin (g/dL)	5.09	0.10	0.64	38	5.13	0.54	1.80	11
Albumin : globulin ratio	0.54	0.01	0.09	38	0.58	0.06	0.21	11
Total bilirubin (mg/dL)	0.10	0.00	0.02	38	0.10	0.00	0.00	11
Direct bilirubin (mg/dL)	0.04	0.01	0.05	38	0.06	0.02	0.05	11
Indirect bilirubin (mg/dL)	0.06	0.01	0.05	38	0.04	0.02	0.05	11
BUN (mg/dL)	17.58	1.50	9.23	38	16.55	2.09	6.95	11
Creatinine (mg/dL)	0.65	0.01	0.06	38	0.73	0.01	0.05	11***
BUN : Creatinine ratio	26.87	2.13	13.15	38	22.65	2.71	8.99	11
Cholesterol (mg/dL)	146.21	5.57	34.35	38	136.55	9.13	30.29	11
Glucose (mg/dL)	111.42	7.99	49.28	38	86.27	8.18	27.14	11
Calcium (mg/dL)	8.53	0.05	0.34	38	9.16	0.15	0.51	11***
Phosphorus (mg/dL)	3.67	0.08	0.51	38	5.68	0.50	1.66	11***
Bicarbonate (mEq/L)	18.16	0.45	2.78	38	17.18	0.72	2.40	11
Chloride (mEq/L)	113.08	0.53	3.27	38	113.55	1.11	3.67	11
Potassium (mEq/L)	4.15	0.04	0.26	38	4.25	0.09	0.31	11
Sodium (mEq/L)	145.87	0.44	2.74	38	146.82	1.13	3.74	11
Sodium/potassium ratio	35.21	0.38	2.34	38	34.64	0.64	2.11	11
Anion gap (mEq/L)	18.76	0.59	3.66	38	20.45	0.94	3.11	11
Hematology								
WBC ($10^3/\mu L$)	15.84	0.63	3.86	38	15.40	1.33	4.41	11
RBC ($10^6/\mu L$)	6.34	0.13	0.82	38	6.30	0.13	0.43	11
Hb (g/dL)	12.76	0.24	1.51	38	12.23	0.27	0.91	11
HCT (%)	40.48	0.73	4.51	38	39.52	0.89	2.96	11
MCV (fL)	64.11	0.38	2.36	38	62.64	0.65	2.16	11*

TABLE 2. Continued.

	Adult				Pup			
	Mean	SE	SD	*n*	Mean	SE	SD	*n*
MCH (pg)	20.17	0.13	0.82	38	19.43	0.18	0.60	11***
MCHC (g/dL)	31.53	0.14	0.87	38	30.99	0.29	0.98	11*
Neutrophil (%)	76.95	1.37	8.46	38	74.36	2.62	8.67	11
Lymphocytes (%)	10.53	0.85	5.25	38	13.64	1.32	4.39	11*
Monocytes (%)	4.58	0.37	2.23	36	3.00	0.50	1.67	11**
Eosinophil (%)	7.14	0.74	4.50	37	7.82	1.59	5.27	11
Basophil (%)	1.95	0.25	1.17	22	3.25	1.11	2.22	4
Absolute neutrophil segment (per μL)	12,292.37	608.96	3,753.86	38	11,537.18	1,202.59	3,988.53	11
Absolute lymphocyte (per μL)	1,623.84	135.10	832.81	38	2,070.45	259.30	860.01	11
Absolute monocyte (per μL)	720.39	65.22	391.33	36	486.27	97.39	323.02	11**
Absolute eosinophil (per μL)	1,065.25	103.97	623.83	36	1,195.18	220.86	732.51	11
Absolute basophil (per μL)	314.04	43.78	209.95	23	467.75	163.72	327.44	4

[a] Standard error.
[b] Standard deviation.
* $P < 0.10$.
** $P < 0.05$.
*** $P < 0.01$.

prove valuable in the continued evaluation of the status of this threatened species.

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